The Use of Seismic Attributes for Submarine Channel Interpretation in Deepwater Taranaki Basin, New Zealand

Kritanol Naewboonnien*

Petroleum Geoscience Program, Department of Geology, Faculty of Science,
Chulalongkorn University, Bangkok 10300, Thailand
*Corresponding author email: kritanol.n@gmail.com

Abstract

The Deepwater Taranaki Basin is considered as undeveloped and unexplored deepwater part of Taranaki Basin. The purpose of this study is to determine the submarine channel complex within Romney-3D seismic data by using seismic attribute and seismic facies analysis. Variance attribute is suitable for outlining the edge of channel complex. Instantaneous frequency attribute is good for observing the detail of architectural elements. Root mean square (RMS) amplitude and sweetness attributes indicate the lithological variation especially sweetness attribute which distinguishes between sandy and muddy lithology. The architectural elements of this study area can be detected by using seismic attributes. Seismic facies analysis is used to confirm the interpretation of these elements. Seismic facies can be categorized into five main facies including overbank deposits, mass transportation complex, inner levee deposits, stacking channel deposits, and point-bar deposits. In this study, seismic facies and seismic attribute are successfully used to define sand distribution mostly associated with basal lag and stacking channel of channel-fill deposits. These deposits may have good porosity and permeability providing a flow unit in submarine channel deposits.

Keywords: Submarine Channel, Seismic Attribute, Seismic Facies, Architectural Element, Sand Distribution

1. Introduction

Deepwater Taranaki Basin lies within the current producing field Taranaki Basin (Higgs et al., 2010) in the western coast of North Island, New Zealand (Figure 1). Majority of production comes from the fields located in offshore shallow water and peninsular regions which had been almost exploited (Uruski, 2008). Recent exploration target has been changed and focused on deepwater frontier areas to search for new potential zones. The Miocene siliciclastic and shale succession of Manganui Formation in this deepwater region is a focus of the study. Within the presence of the submarine channel, several studies had been taken to observe the geomorphology of the channel (Grahame, 2015) and lithology of infilled sediment (Li et al., 2017). According to those studies, seismic attributes were used and become an important tool for extracting details of channel architectural elements leading to interpretation of reservoir distribution. However, the use of seismic attribute and seismic facies analysis has not been conducted in this area. This study is aimed to compare the use of each seismic attribute and to determine the reservoir distribution in Miocene submarine channel system.

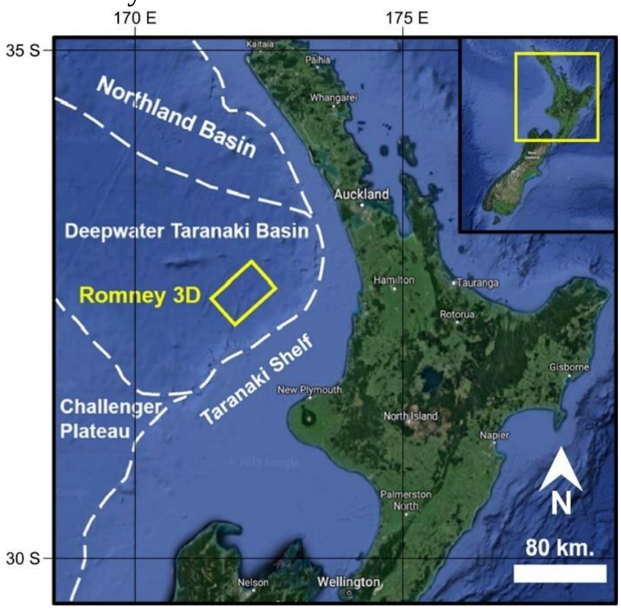

Figure 1. Location of Deepwater Taranaki Basin and study area "Romney – 3D" seismic survey.

2. Geological setting

Deepwater Taranaki Basin had been evolved during Late Cretaceous when New Zealand was a part of Gondwana active continental margin (Sutherland et al., 2001). The subduction was ongoing caused the back-arc terrane to become rifted and subsided. New Caledonia Basin was formed during this time and accumulated by terrestrial sediments from Taranaki delta (Rakopi Formation). Opening of Tasman Sea was occurred thereafter and marked with the deposition of transgressive sequence of North Cape Formation. During Middle Eocene, the northwestern part of the basin underwent gentle folding caused folds and faults in Deepwater Taranaki Basin (Uruski et al., 2002). In Late Oligocene, the modern plate boundary of Indo-Australia and Pacific plate was developed. New Zealand terrane was uplifted and provided the source of clastic sediments. During Middle Miocene, large amount of sediment was widely deposited across the shelf and deepwater area. Turbidite successions formed as the terrestrial sediments were eroded from the hinterland. Submarine channel systems were incised into the Early Miocene succession and characterized by mounded feature at the upper part. In Pliocene, large mass transportation complexes of Giant Foresets Formation were deposited. Overlying the Pliocene unit, active small submarine channels had carved the present-day seabed.

3. Seismic attributes analysis

In this study, the amplitude enhancement and structural attributes were applied to the seismic volume. Amplitude enhancement attributes are comprised of root mean square (RMS) amplitude, instantaneous frequency and sweetness attributes. Structural attribute used in this study is variance attribute.

3.1 Variance attribute

Displaying variance attribute on seismic time slices gives a clear image of submarine channel complex. As illustrated in figure 2a, the edge of main submarine channel is clearly defined by the highlighted channel margin with high value of variance. The higher value is corresponded with the zone of discontinuity such as the zone between the channel-fill deposits and outer levee. High variance magnitude is also presented in meandered loop characterized by the arch-like black lines separating each scroll bar apart. Summarily, variance attribute helps accentuate the discontinuity in seismic data especially in submarine channel complex where the boundary of channel becomes an important issue.

3.2 Root mean square (RMS) attribute

In figure 2b, it can be observed that the channel-fill deposits in northwestern part shows a relatively low amplitude compared with the adjacent outer levee. Point-bar deposits are also shaded in light to dark blue indicating a low amplitude. In contrast, the southeastern outer levee deposits tend to have a higher amplitude colored in bright red to yellow tone. In general understanding, the bright spot can be involved with the presence of hydrocarbon within the sandy interval. However, the change of acoustic impedance from low to high magnitude can show the resemble outcome. So, the application of RMS amplitude attribute should be used with awareness as it is sensitive with the change of acoustic impedance.

3.3 Instantaneous frequency attribute

Northwestern part of the active main channel is illustrated by green to greenish blue and tinted with little red spots near the edge of channel margin (Figure 2c). Along the northwestern part to middle part of submarine channel complex, the point bar displays a variety of color ranging from low to high frequency. While, the migration of meandered loops in the middle to southeastern part of submarine channel complex shows a switching band of higher and lower frequency color tone in each scroll bar. Moreover, the areas outside the channel complex (e.g. outer levee deposits) typically show a lower frequency representing in red to yellow tone in the southeastern part. Hence, lithological variation can be roughly made by observation of the instantaneous frequency in each part of submarine channel complex. High frequency events can be resulted from the thin shaly interval. Low frequency events can be occurred from rich-sand beddings due to fluid content the pores and fracture zones. So, the instantaneous frequency attribute can

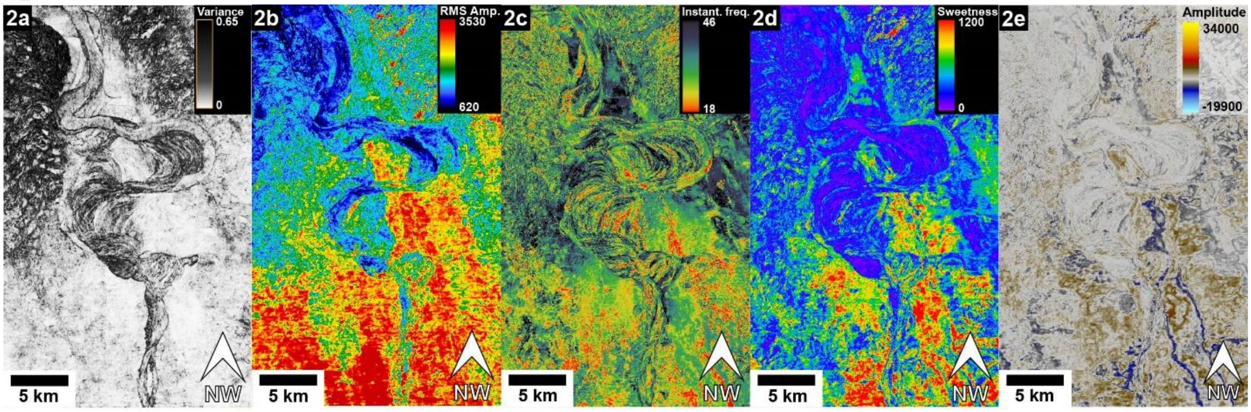

Figure 2. The time slice at -2800 ms of submarine channel complex. **(2a)** Variance attribute showing a highlighted channel margin **(2b)** Root mean square attribute showing a low amplitude along the main channel **(2c)** Instantaneous frequency attribute illustrating many details in the point bar and migration of meandered loops zone **(2d)** Sweetness attribute displaying a relatively lower value in the northwestern part in main channel and point-bar zone. **(2e)** Default seismic amplitude

distinguish the sand/shale proportion in clastic environment.

3.4 Sweetness attribute

Using sweetness attribute shows less observation on channel margin (Figure 2d). The low sweetness value is represented in blue to purple tone which can be found in the northwestern part of submarine channel complex especially in point-bar and main channel. In middle to southeastern part, the low sweetness value is also dominated in the migration of meander loops zone. On the contrary, the zone of higher sweetness value in yellow to red tone is mainly distributed in the middle to southeastern outer levee deposits. To conclude, the change in sweetness value may be influenced by the lithological variation.

3.5 Co-rendered seismic attributes

The opacity of amplitude enhancement attributes including instantaneous frequency, root mean square amplitude and sweetness attributes were adjusted to 40% and applied on variance attribute.

3.5.1 Co-rendered instantaneous frequency attribute

Focusing on the area outside the outer levee (Figure 3), mass transportation complexes (MTC) can be seen by rugged and chaotic seismic reflection bordered by the sharp edges (especially in southwestern MTC) adjacent to the outer levee of submarine channel complex. The frequency within the MTC is varied on both sides. Outer levee deposits can be defined by the area outside the active main submarine channel (bounded by thick black line) excluding the MTC and point-bar deposits with smooth seismic reflection. In the northwestern region, outer levee deposits tend to have a higher instantaneous frequency. While, the middle outer levee deposits which surrounded by two packages of migration of meandered loops and point-bar deposits have a relatively lower frequency. Similarly, the northwestern outer levee deposits are low in frequency explained by the presence of yellow to red tone color scale. There are six abandoned channels detected. All abandoned channels are located within the outer levee deposits and can be distinguished (in dashed lines) by moderate relief of small channel margins and sometimes the abrupt change in frequency from higher outer levee to lower abandoned channel. Within the channel complex, the lateral movement of the channel can be shown by the evidence of point-bar deposit and migration of meandered loops. Two point-bar deposits (in white dashed lines) are portrayed by the paralleled layers of varying frequency colors bounded by the edge of channel inner bend. Compared with other co-rendered attributes, co-rendered instantaneous frequency attribute gives the high-resolution details in point-bar deposits. Difference lithology and depositional style can be indicated by the varying in frequency color in each layer. Migration of meandered loops can be found within the main active channel or outer levee adjacent to the outer bend edge of submarine channel. It can be detected by the presence of scroll bars interpreted by the black sketched sigmoid-like lines. Moreover, the co-rendered attribute displays a feature of former single terrace at the edge of channel outer bend. Summarily, co-rendering of instantaneous frequency and variance help interpreters to understand the complexity of highly evolved stratigraphic feature such as migration of meandered loops and point-bar deposits.

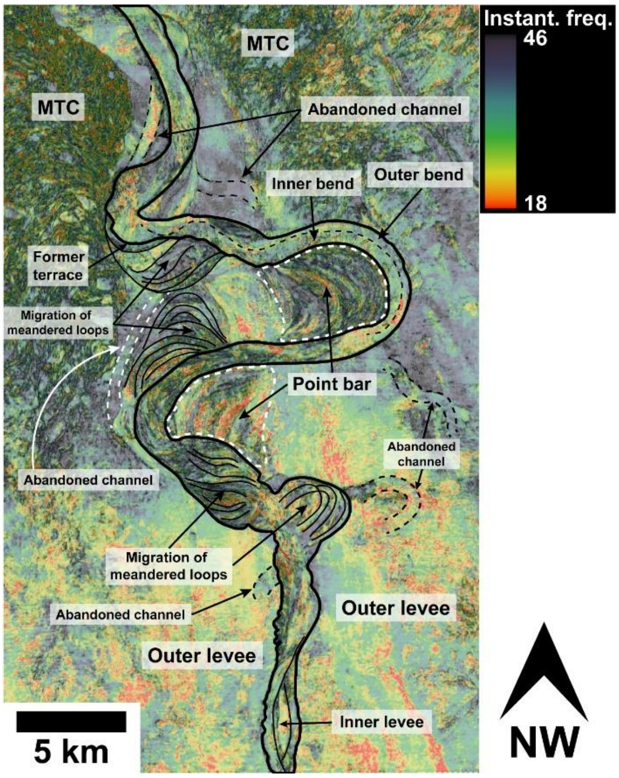

Figure 3. The co-rendered instantaneous frequency attribute image at -2800 ms unveiling the stratigraphic features and architectural elements of submarine channel complex.

3.5.2 Co-rendered root mean square amplitude attribute

The result from co-rendered root mean square amplitude attribute with variance defines the presence of architectural elements and stratigraphic features slightly different from instantaneous frequency. The additional architectural element observed in this co-rendered seismic attribute is possible mid-channel bars in active main channel (Figure 4). Those mid-channel bars are characterized with the higher amplitude bar shaped within the channel which can be implied to the presence of sandy lithology surrounded by shale-dominated interval. The distribution of amplitude color scale along the main active channel displays the trend of lower amplitude in the northwestern region and relatively higher one in southeastern region. In high sinuous middle to southeastern part, the active main channel shows the higher amplitude color on the outer bend indicating the deposition of coarse-grained materials in high energy regime. Point-bar deposits and migration of meandered loops tend to represent a more homogeneous amplitude color compared with instantaneous frequency color. The outer levee resolved in this co-rendered image exhibits the higher amplitude in the southeastern to middle part whereas the northwestern region is lower. The detection of abandoned channels in co-rendered root mean square amplitude attribute is more difficult than co-rendered instantaneous frequency. At least two abandoned channels were resolved with insignificantly different geometry. Detail of scroll bars in migration of meandered loops is also less observed than the frequency co-rendered attribute. To sum up, the root mean square amplitude attribute co-rendered with variance is good for differentiating each part of submarine channel complex based on the variation of amplitude intensity in each specific zone.

3.5.3 Co-rendered sweetness attribute

Result of sweetness co-rendered attribute (Figure 5) shows a low sweetness value within the southwestern MTC. Conversely, the northeastern MTC displays many blocks of debris deposits with prominently higher sweetness. Migration of meandered loops zone and point-bar deposits are also low in sweetness value. The migration of scroll bars is hard to define in migration zone as the sweetness value is quite small making the detected edges from

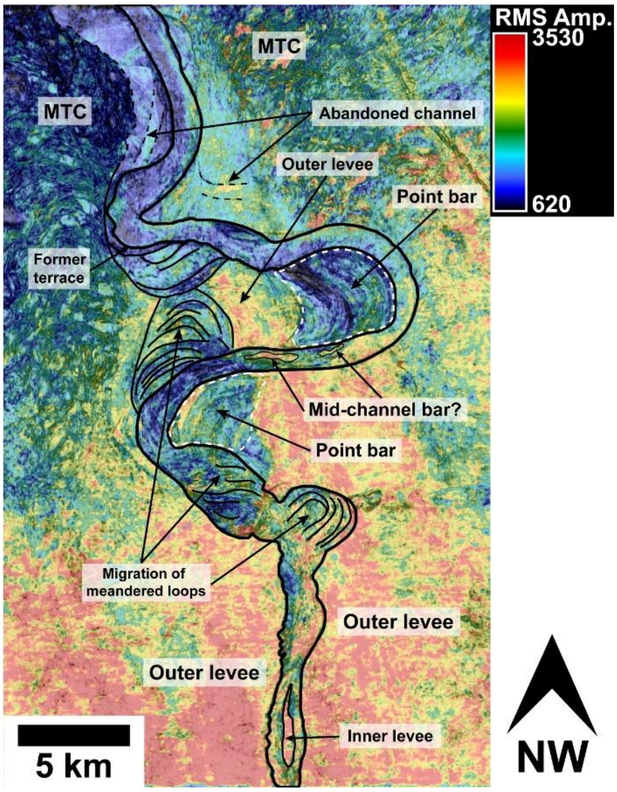

Figure 4. The co-rendered root mean square attribute image at -2800 ms can portray the zone of high and low amplitude variation among the submarine channel elements.

variance smeared out. Like former terrace deposits, the terrace cannot be clearly identified in this co-rendered seismic attribute as there is low contrast of sweetness intensity between main active channel and levee. Northwestern outer levee deposits are mainly represented by the low sweetness (purple tone). However, in some area where the abandoned channels had been resolved the sweetness value will raise up shown by bluish green tone. The sweetness value of outer levee deposits becomes higher toward the southeast mostly showing in yellow to red tone. In main active channel, sweetness shows a wide range of color through the entire channel. The low and moderate values are dominated in the northwestern part in high sinuosity region. Sweetness value is abruptly changed in the zone of migration of meandered loops within the main active channel to relatively higher value observed by yellow to red tone. In the southeastern part, sweetness appears to range from moderate to high value. To summarize, the change in sweetness color scale in each architectural element can indicate the lithological variation controlled by the submarine channel process.

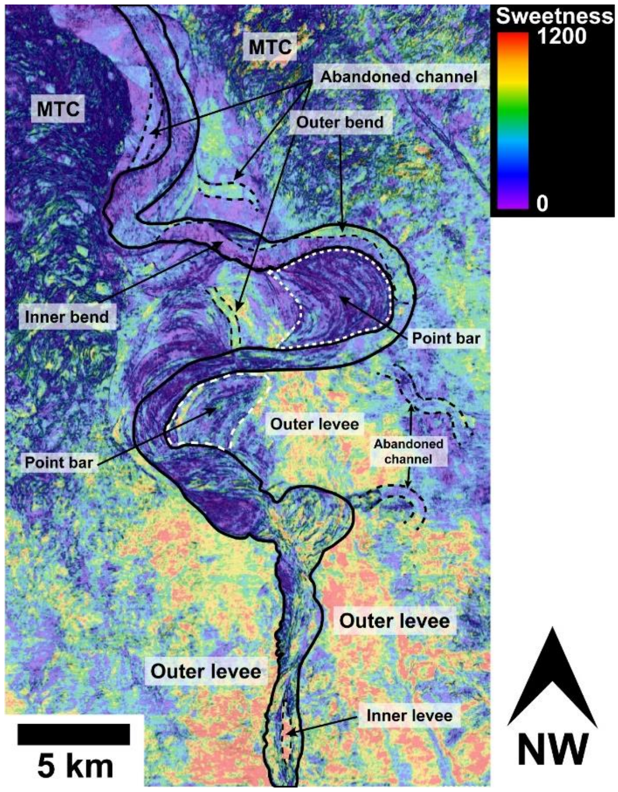

Figure 5. The co-rendered sweetness attribute image at -2800 ms indicating lithological variation in submarine channel complex

Co-rendering seismic attribute with variance attribute helps interpreters resolve more details of architectural elements. Without variance attribute, the edge of each element will not be detected. Application of amplitude enhancement attributes can help explain the evolution of migration of submarine channel as well as the lithology of sediments in many parts of channel. The sketch in figure 6 illustrated the important architectural elements within the submarine channel complex observed by using co-rendered seismic attributes.

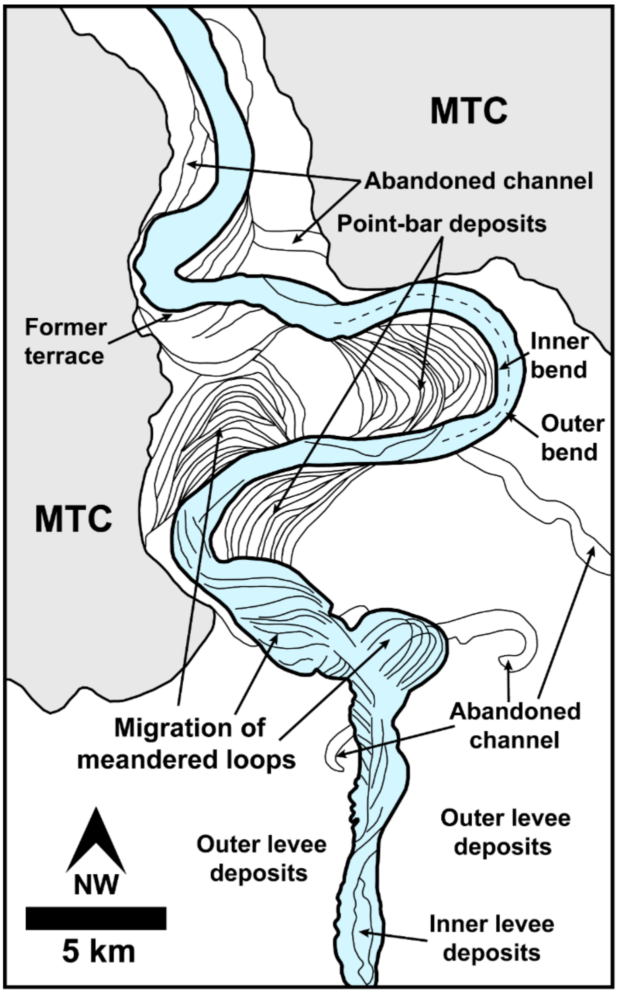

Figure 6. The schematic interpretation illustrating the submarine channel complex architectural elements, main active submarine channel was bordered in thick black line and highlighted in pale blue whereas mass transportation complexes (MTC) were shown in grey.

4. Seismic facies analysis

Seismic facies classification is based on the property of seismic reflection comprised of configuration, continuity, frequency and amplitude. In this study, seismic facies was applied for defining the reservoir distribution. There are five seismic facies associated with submarine channel complex had been described as follow.

4.1 Seismic facies 1

This seismic facies is characterized by high-amplitude, steadily continuous seismic reflection with gently inclined to sub-paralleled orientation. It is associated with the mound surface and typically formed outside the submarine channel complex adjacent to the channel wall. Based on the observation of seismic reflection, the facies can be interpreted as overbank deposits.

4.2 Seismic facies 2

It is comprised with the moderately high amplitude, chaotic discontinuous seismic reflection. It can be found outside and above the mound surface of submarine channel complex. It exhibits the features of slump and slide deposits and can be characterized as mass transportation complex.

4.3 Seismic facies 3

The facies is represented by the moderately low amplitude, continuous to discontinuous seismic reflection with sub-paralleled configuration. The facies is found within the submarine channel complex confined to the channel wall which can be defined as channel-fill deposits. But, in this case, the geometry of this seismic facies implies the levee-like shape. As it formed in the within the channel complex, it can be established as inner levee deposits.

4.4 Seismic facies 4

The facies is composed of high amplitude, continuous seismic reflection with paralleled orientation, occurred within the submarine channel complex. It can be interpreted as a kind of channel-fill deposits. Moreover, the time slice passed through this seismic unit shows a clear result of an active channel. So, this facies can be categorized as stacking channels.

4.5 Seismic facies 5

This facies is shown by moderately high amplitude, continuous to discontinuous seismic reflection with shingled configuration. The reflection termination is downlapped to the overbank deposits. It can be interpreted as point-bar deposits.

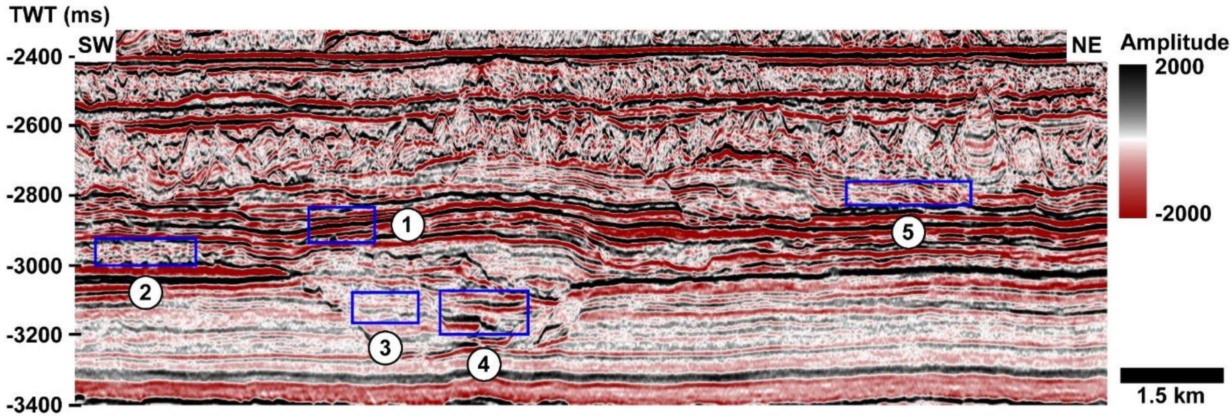

Figure 7. Seismic section in red-white-black color scale showing observable five seismic facies: 1. High amplitude, continuous reflection with gently inclined to sub-paralleled orientation 2. Moderately high amplitude, chaotic discontinuous reflection with irregular orientation 3. Moderately low amplitude, continuous to discontinuous reflection with sub-paralleled configuration 4. High amplitude, continuous reflection with paralleled orientation 5. Moderately high amplitude, continuous to discontinuous reflection with shingled configuration.

5. Discussion

5.1 Seismic attributes comparison

In the aspect of morphology and geometry of submarine channel complex, variance attribute alone is the most suitable attribute to image the edge and extent of many architectural elements. While, the instantaneous frequency attribute is more resolvable than sweetness and root mean square amplitude attributes. The amplitude enhancement attributes like sweetness and root mean square amplitude attributes can display an image of channel trend but not for the channel edge detection. To observe the detail of architectural elements, the instantaneous frequency attribute provides the clearest image of submarine channel complex elements. Abandoned channels, point bar-deposits and migration of meandered loops are principal elements which clearly accentuated from this attribute. The lateral migration is confirmed by the evolution of scroll bars seen in migration of meandered loops. Without the visualization from instantaneous frequency attribute, the understanding in submarine channel development may be hardly defined.

In terms of lithological interpretation, the use of sweetness attribute is good for delineating the variation of sedimentary rock. High sweetness value suggests the possible coarser sandy interval whereas the relatively lower value tends to represent finer mud-rich interval. As sweetness is derived from reflection strength of amplitude and instantaneous frequency, those hypotheses will be only a general rule of thumb. High sweetness value can be caused by the anomalous high acoustic impedance contrast event such as overpressure zone and highly cemented interval. So, the high sweetness does not represent the existence of hydrocarbon-filled reservoirs at all. In this study, for submarine channel complex, the difference in sweetness value indicates the lithological change related to the depositional characteristics of this area.

5.2 Sand distribution in submarine channel complex

According to figure 8a, the submarine channel complex was in the initiation development stage. Considering in northwestern part, the presence of high sweetness was related with channel-fill deposits. In this early-forming submarine channel complex, the channel-fill sediments probably comprised of coarse-grained material ranges from gravelly-lag deposits to sand-size sediments forming an erosional incision to the older sediments. Sandstone was dominantly accumulated in this high energy environment. As the basal part of channel had been filled, the lateral migration and vertical stacking was occurred

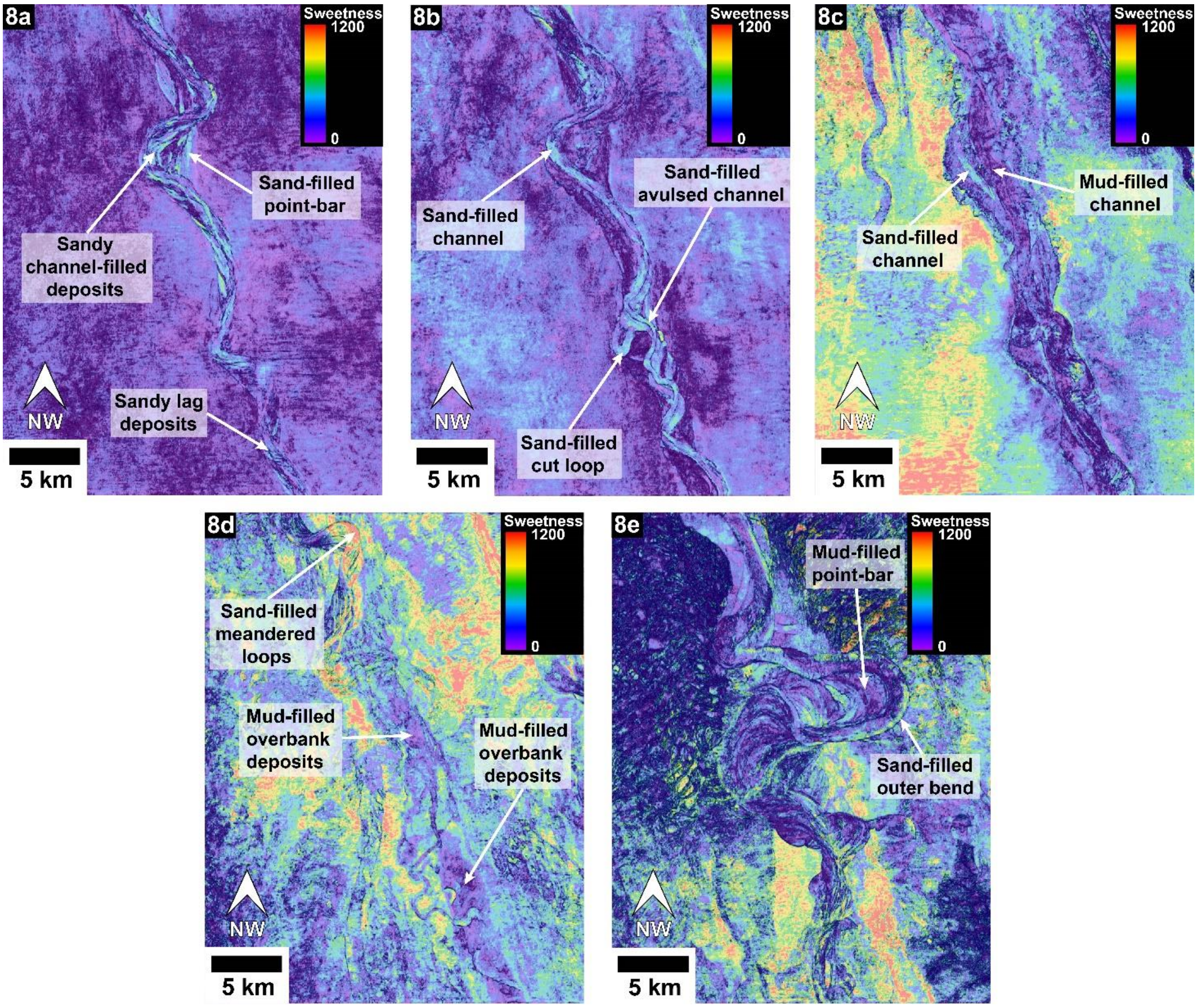

Figure 8. Co-rendered sweetness attributes illustrate the evolution started at the erosional base to the uppermost part of submarine channel. **(8a)** Time slice at -3240 ms shows the early development stage of submarine channel complex. The probability of sand deposition is high in this phase due to the high energy of erosive flow comprised of coarser materials. **(8b)** Time slice at -3140 ms illustrates the sand-filled channel and cut loop. The avulsion could be occurred by the strong flow resulted in the abandonment of former channel loop. Sand deposits are associated with the avulsed channel because of this process. **(8c)** Time slice at -3020 ms displays a submarine channel complex at its middle channel height. The most dominant sediment in this part is mud. Sand deposits are rare and can be found in some channel meandered loops. **(8d)** Time slice at -2900 ms shows a disappearance of channel complex margin due to the deposition of overbank deposits dominated by muddy sediments. The presence of sand can be observed in the upper part of the image at the migrated meandered loops. **(8e)** Time slice at -2780 ms portrays the submarine channel complex at its late stage of development indicated by the lateral movement of channel. The supplied sediments were unconfined with the main channel complex shown by the laterally migrated point-bar and meandered loops. Sand distribution is associated with the outer bend of meandered channel due to its higher depositional energy.

subsequently. The slope along the channel axis could be reduce resulting in the development of sinuosity (Figure 8b). Sandy lithology was dominated in the cut loop and avulsed channel observed by high sweetness value. The avulsion could be occurred by the erosive high energy flow resulted in the abandonment of older channel loop. The flow might be influenced by the presence of coarse-grained sediments forming a sandy avulsed channel. In a middle of channel height (Figure 8c), sweetness shows a lack of sandy deposits. The main submarine channel was dominated by muddy channel-fill sediment shown by very low sweetness value. This could be caused by the starvation of coarse-grained sediment or may be the low sedimentation rate providing deposition of hemipelagic mud. At this stage, the submarine channel complex was nearly filled with channel-fill deposits. The topography within the channel could be at the same level of the outer levee crests resulted in the scarcity of accommodation space. This condition provided the accumulation of fine-grained overbank deposits shown by low sweetness value and the disappearance of channel complex margin (Figure 8d). The existence of sandy deposits is mainly accumulated in northwestern region in migrated meandered loops. In the uppermost part of submarine channel complex (Figure 8e), the deposited sediments were not confined to the main submarine channel. The evidence is supported by the lateral movement expressed by point-bar deposits and migration of meandered loops packages. Sand distribution can be detected in outer bend of channel and southeastern migrated meandered loops, but the point-bar deposits are dominated with mud.

5.3 Petroleum application

Based on sand distribution analysis, the deposition of coarse-grained sediments are mainly accumulated in channel-fill deposits of basal to middle lower part of submarine channel complex. The channel-fill deposits are consisted of basal lag deposits and stacking channel deposits confined within the channel complex. Lithologically, these deposits may have a characteristic porosity and permeability providing a flow unit in submarine channel setting. Basal lags deposits are bounded with the overlying muddy inner levee deposits and lower underlying fine-grained sediments of Manganui Formation. With low porosity and permeability property, the surrounded fine-grained sediments may prevent the fluid flow in vertical direction. However, the lateral continuity of each sand body can be observed in the lowermost part of channel. In the same way, the stacking channel deposits are also bounded with the mud deposits resulted in the restricted fluid flow. Summarily, the submarine channel complex is dominated with muddy sediments and the connectedness of sand body is only lateral continuity. The aggradation of channel stacking is presented with muddy sediments. So, in aspect of reservoir characterization, the sand bodies are laterally well-connected in the lowest part but become lack in vertical dimension. The illustration of sand distribution in vertical seismic profile is shown in figure 9.

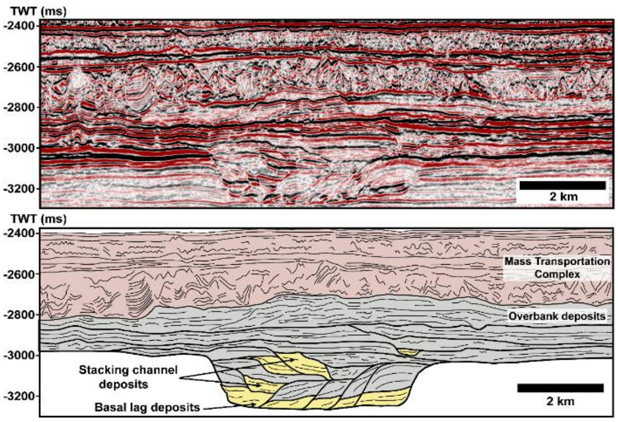

Figure 9. Schematic sketch of submarine channel complex shows sand distribution at the basal lag deposits and stacking channel fill deposits.

6. Conclusions

1. The architectural elements observed from the use of seismic attributes in this study are abandoned channel, submarine channel margin, migration of meandered loops, point-bar, levee, terrace and possible mid-channel bar.
2. Variance attribute outlines the structure and geometry of submarine channel complex as well as the stratigraphic features. Instantaneous frequency attribute provides the great ability for architectural elements detection in delicate details. Root mean square and sweetness attribute enhances the lithological determination especially sweetness attribute for defining sand distribution. Co-rendered seismic attribute is the powerful tool for simultaneously imaging structural and stratigraphic features.

3. Seismic facies in submarine channel complex can be categorized into five facies: overbank deposits, mass transportation complex, inner levee deposits, stacking channel fill deposits and point-bar deposits.
4. Sand accumulation in submarine channel complex are associated with channel-fill deposits which are basal lag deposits and channel stacking deposits.

7. Acknowledgements

My gratitude is given to Petroleum Geoscience Program, Department of Geology, Chulalongkorn University for providing me the academic scholarship.

I would like to extend my appreciations to my supervisor Assistant Professor Dr. Piyaphong Chenrai for his valuable suggestion and supportive assistance during my master's degree course. My respect is also given to Professor Angus John Ferguson, Professor John Keith Warren, and other visiting professors for fulfilling me an applicable knowledge.

I would like to thank to my classmate for a plenty of enjoyable moments in our classroom and in the field.

My deepest thanks are given to my family and Ms. Pornpipat Sa-ngam who always cheer me up in my past tough time with their optimistic encouragements. Without you all this work could not be achieved.

8. References

Grahame, J., 2015. Deepwater Taranaki Basin, New Zealand—New Interpretation and Modelling Results for Large Scale Neogene Channel and Fan Systems: Implications for Hydrocarbon Prospectivity, in: International Conference and Exhibition, Melbourne, Australia 13-16 September 2015. Presented at the International Conference and Exhibition, Melbourne, Australia 13-16 September 2015, Society of Exploration Geophysicists and American Association of Petroleum Geologists, Melbourne, Australia, pp. 518–518.

Higgs, K.E., Arnot, M.J., Browne, G.H., Kennedy, E.M., 2010. Reservoir potential of Late Cretaceous terrestrial to shallow marine sandstones, Taranaki Basin, New Zealand. Marine and Petroleum Geology. 27: 1849–1871.

Li, Q., Yu, S., Wu, W., Tong, L., Kang, H., 2017. Detection of a deep-water channel in 3D seismic data using the sweetness attribute and seismic geomorphology: a case study from the Taranaki Basin, New Zealand. New Zealand Journal of Geology and Geophysics 60, 199–208.

Sutherland, R., 2001. Tectonic Evolution of Cretaceous Rift Basins in South-Eastern Australia and New Zealand: Implications for Exploration Risk Assessment 11.

Uruski, C.I., Stagpoole, V., Isaac, M.J., King, P.R., Maslen, G., 2002. Seismic Interpretation Report – Astrolabe Survey, Taranaki Basin, New Zealand. Institute of Geological & Nuclear Sciences confidential client report 2002/70 (unpublished). 70 Crown Minerals open-file Petroleum report 3072, Ministry of Commerce, Wellington.

Uruski, C.I., 2008. Deepwater Taranaki, New Zealand: structural development and petroleum potential. Exploration Geophysics 39, 94-107.